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Brigham Young University
Department of Civil Engineering

September 3, 1981

This is the second quarter report for the research project "HCMM Hydrological Analysis in Utah". Our work accomplished during this period was primarily in the areas of temperature calibration, algae detection, evaporation estimation, and groundwater depth location. Additional work with color graphics analysis has also been done.

This study is progressing normally with no major problems encountered. We hope you will find this publication useful and we certainly welcome any comments.

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Associate Professor of Civil
Engineering

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HCMM HYDROLOGICAL ANALYSIS IN UTAH

SECOND QUARTER REPORT

Data Update

At the writing of the first quarter report all but four of the data sets originally ordered had been received. Since that time one set has arrived and the remaining three are still being anticipated. Missing are two night infrared (NIR) images and one day infrared (DIR) and visible (DV) set. The positive prints for these scenes have arrived and look very interesting and the data sets are anxiously awaited. Meanwhile, of course, significant progess on the analyses of the other 35 images has been made.

Calibration

The correlation between HCMM intensities converted to temperatures and the ground truth temperatures has been studied intensively. The question of what, if any, offset value needed to be added to the HCMM User's Manual conversion equation was addressed. When this was resolved, at least for the Utah Lake study area, the effects of several hydrological parameters were investigated.

Offset Determination. The User's Manual second edition states that effectively 5^{o}C had been subtracted from the original HCMM temperatures, but that based on subsequent information some offset value should be added back to the HCMM temperatures. One objective of the present study was to determine if the suggested value of 5.5^{o}C was accurate. HCMM temperatures for days within $\pm$ 5 days of ground truth measurements were calculated using incremental offset values from 4.4 to 5.4^{o}C. The residuals (differences)

between these HCMM temperatures and all of the available lake surface temperature measurements were then determined. The sum of the squares of these residuals (SSR's) were then plotted against the offset values. The minimum SSR corresponds to the best offset and was found to be 4.7 for this data set.

The relationship between HCMM and ground truth measurements taken on different days showed significant unexplainable scatter, whereas for the same day measurements, the correlation was very good. Therefore, the SSR versus offset curve was replotted using only same day data and is shown in Figure 1. The resultant offset of 4.9°C was considered to be the optimum value for this study and has been utilized accordingly.

Further analyses suggest that this offset may vary somewhat with time, location, and surface temperature. The ordinates in Figures 2, 3, and 4 are measured surface temperatures minus HCMM temperatures which include the 4.9°C offset. These values are called "Residual 1". July, September, and November show approximately zero residuals; i.e., very good calibration with the 4.9 value (Figure 2). However, offsets of approximately 6 in August and approximately 4 in October appear to be more appropriate.

Utah Lake was divided into four segments; Goshen Bay (GB), Provo Bay (PB), Central Lake (CL) and North Lake (NL) as shown in Figure 5. Zero residuals are shown in for NL and GB, but CL and PB may be better represented by offsets of approximately 4 and approximately 6°C respectively (Figure 3). Low and high surface temperatures also correspond well with the 4.9 offset, but middle range temperatures; i.e., 15-20°C, appear to correspond better with a 3 or 4°C offset (Figure 4).

<u>Hydrological Parameters</u>. Ground truth surface temperatures minus same day HCMM temperatures were also plotted against several hydrological parameters in order to identify any measureable effects. (These HCMM temperatures do <u>not</u> incorporate the 4.9°C and the resulting residuals are called "Residual 2".)

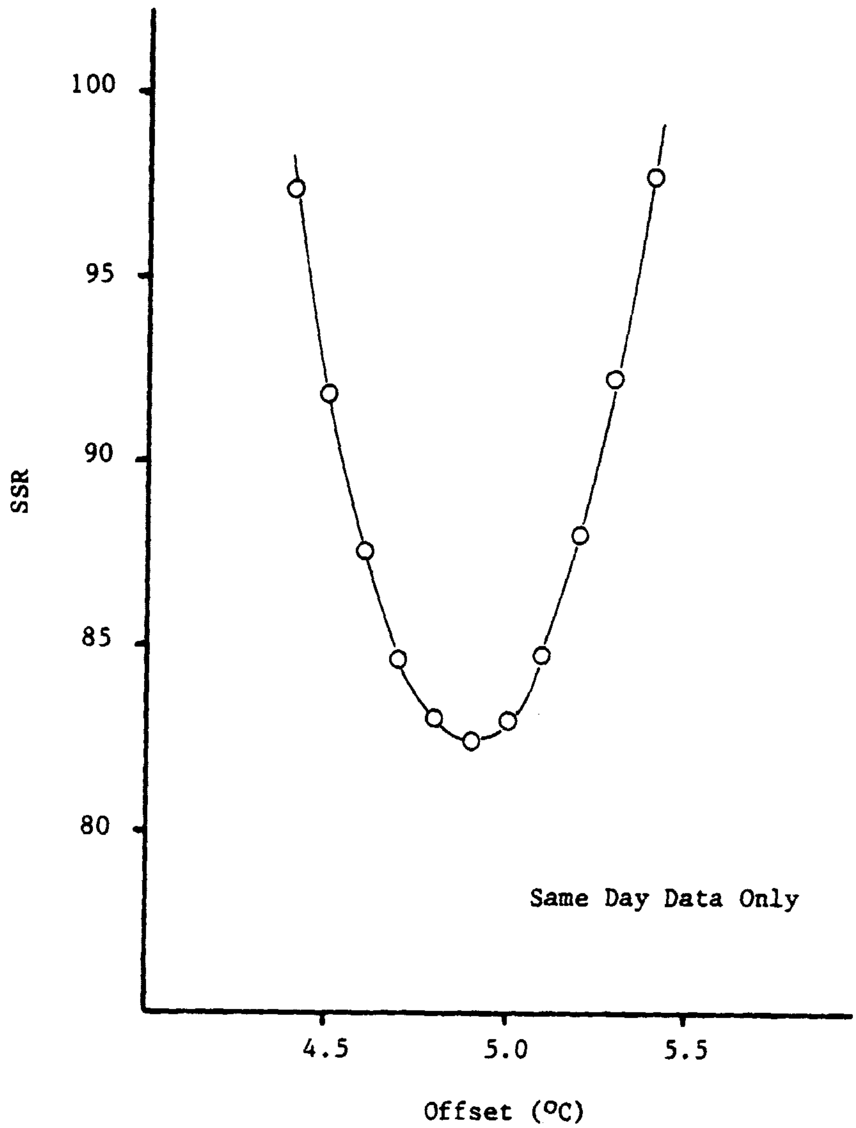

Figure 1. SSR VS. OFFSET

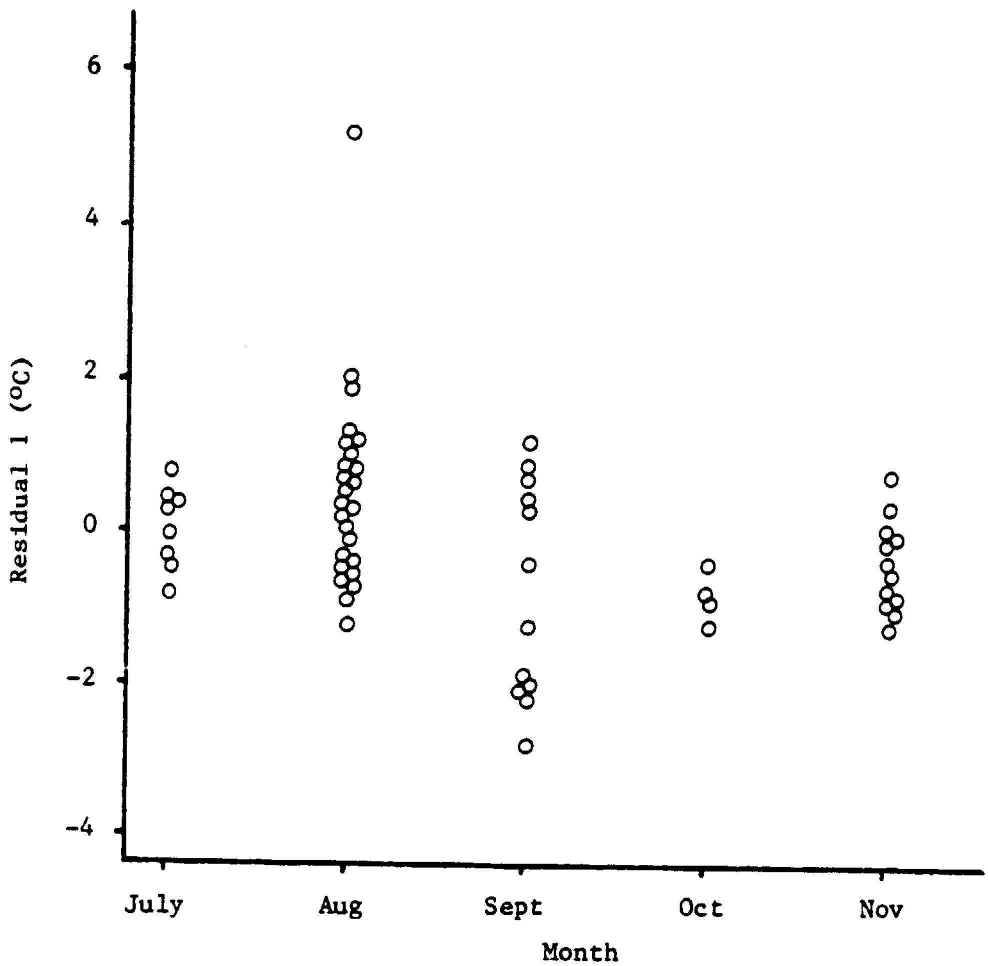

Figure 2. RESIDUAL 1 (MEASURED TEMP. MINUS HCMM TEMP. WITH 4.9 °C OFFSET) VS. MONTH

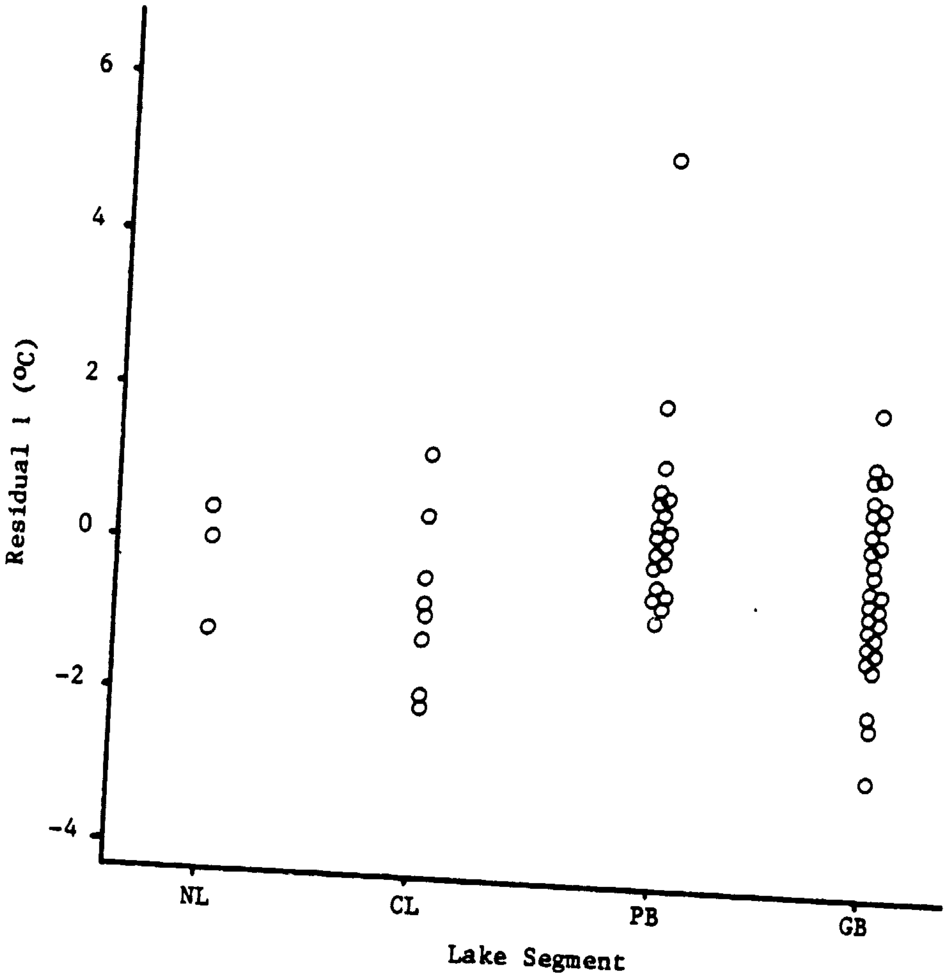

Figure 3. RESIDUAL 1 VS. LAKE SEGMENT

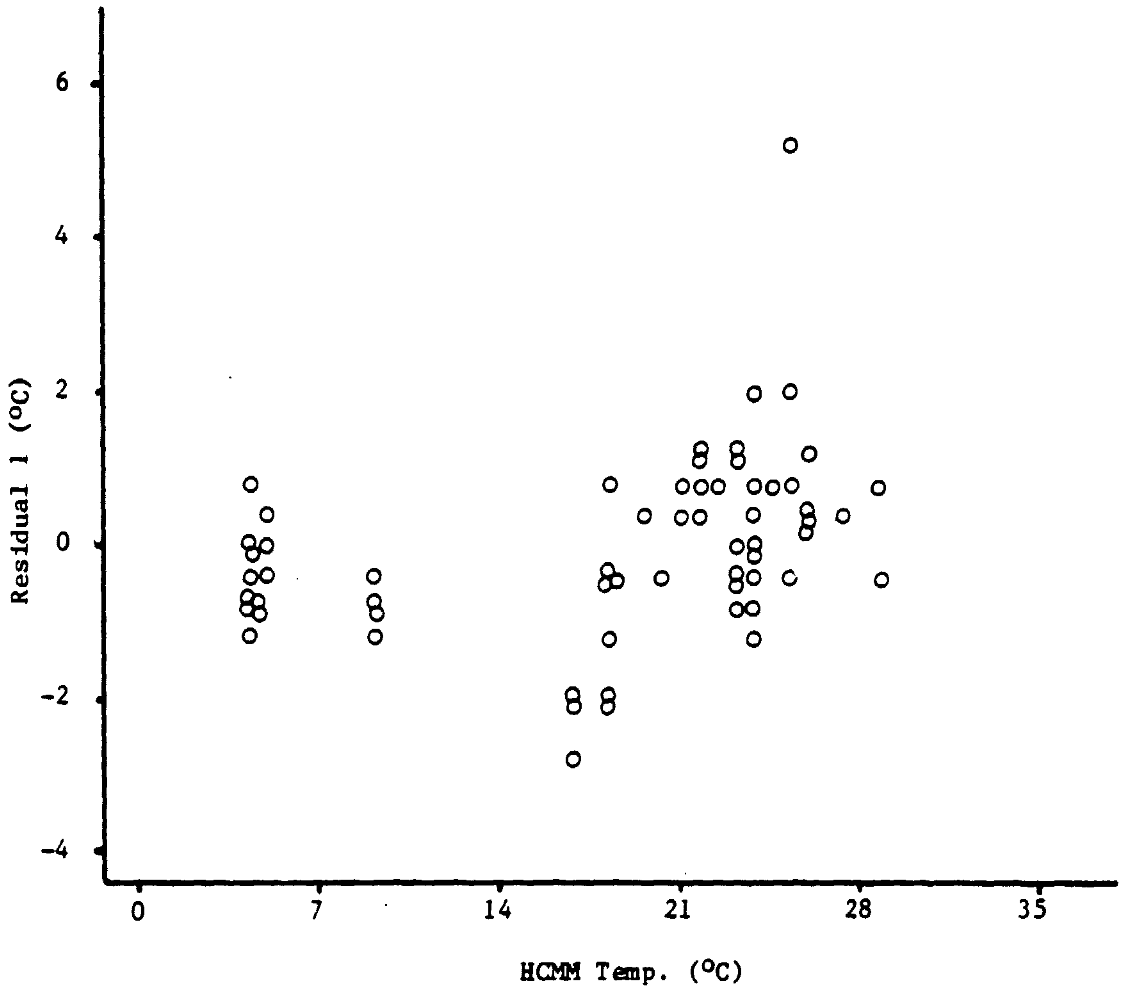

Figure 4. RESIDUAL 1 VS. HCMM TEMP.

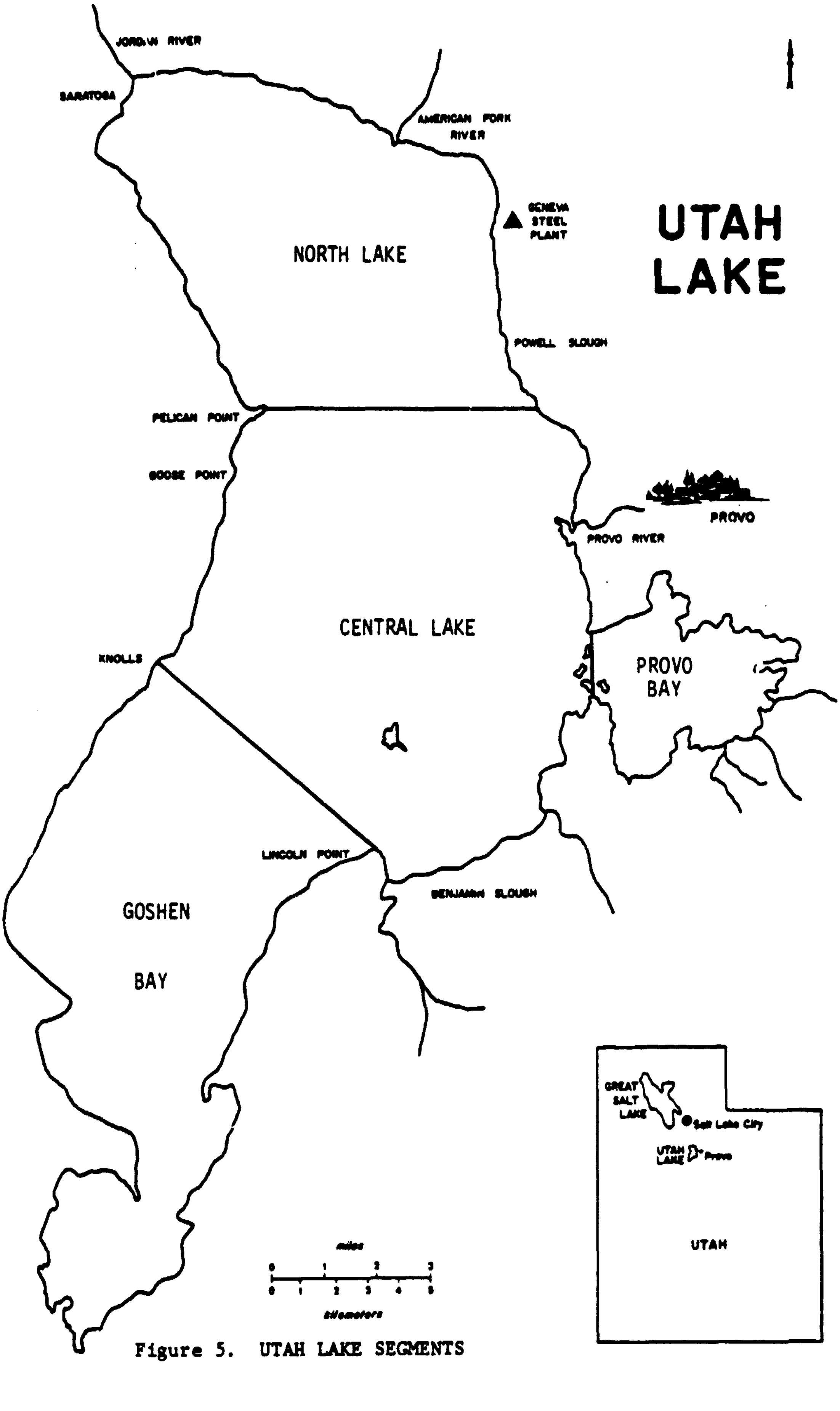

Figure 5. UTAH LAKE SEGMENTS

In Figures 6, 7, 8, and 9 the 4.9 offset doesn't appear to change or be affected by humidity, wind (over the Lehi pan), average pan temperature, nor solar radiation respectively. There were also no perceptable effects by these parameters on the offset when all the ± 5 day data were plotted. In the case of humidity this was an unexpected result (Figure 10).

However, with increases in average air temperature, evaporation, and lake stage, it may be argued that the offset value should increase somewhat (Figures 11, 12, and 13). This is most pronounced for the air temperature. The lines are only best-fit visual approximations. These figures are for same day data. When all the ± 5 day data were plotted these slightly percepable trends disappeared. The reason for this is as yet unclear.

Visible, Thermal, and Algae Relationships

Since the first quarter report particular attention has been given to the relationships among visible data, thermal data, and algae concentrations. Methods have been developed using combinations of the HCMM day infrared (DIR), day visible (DV), and night infrared (NIR) to detect and interpret; (1) the existence of significant algae concentrations, (2) the change in predominance of one algae species to another, and (3) the location, extent, and durration of algal blooms.

Algae Detection. A comparison of algae concentrations as measured at stations throughout Utah Lake during the summer of 1978 and the corresponding HCMM DIR measurements yielded an average correlation coefficient of -0.8 (Figure 14). For an open, natural system statistical correlations greater than 0.7 are considered significant. At night, the algae and NIR data yielded a negative correlation coefficient of -0.92. Until mid-August, the inverse correlation between algae and DV measurements was very high at -0.96 (Figure 15).

Combinations of these significant correlations provide three useful

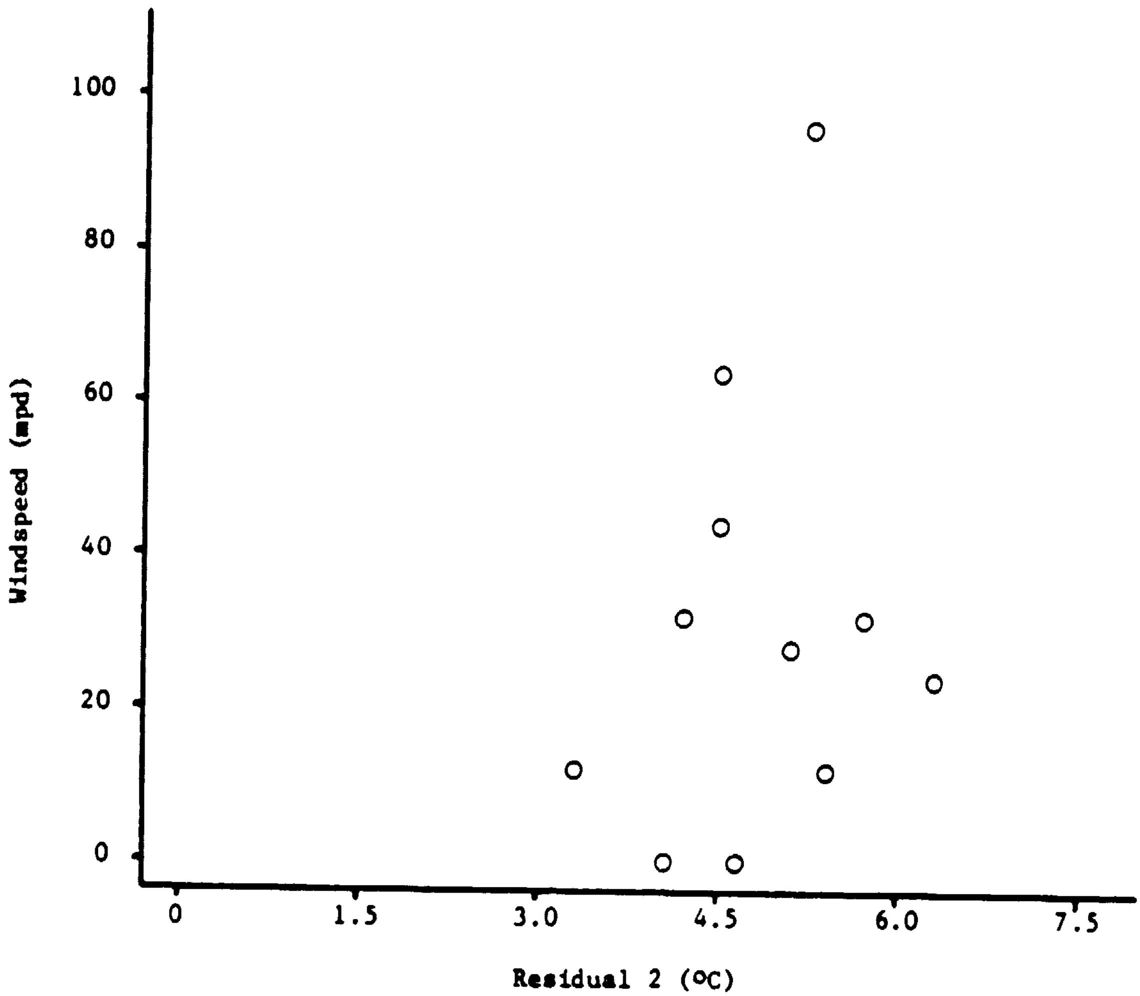

Figure 7. WINDSPEED VS. RESIDUAL 2

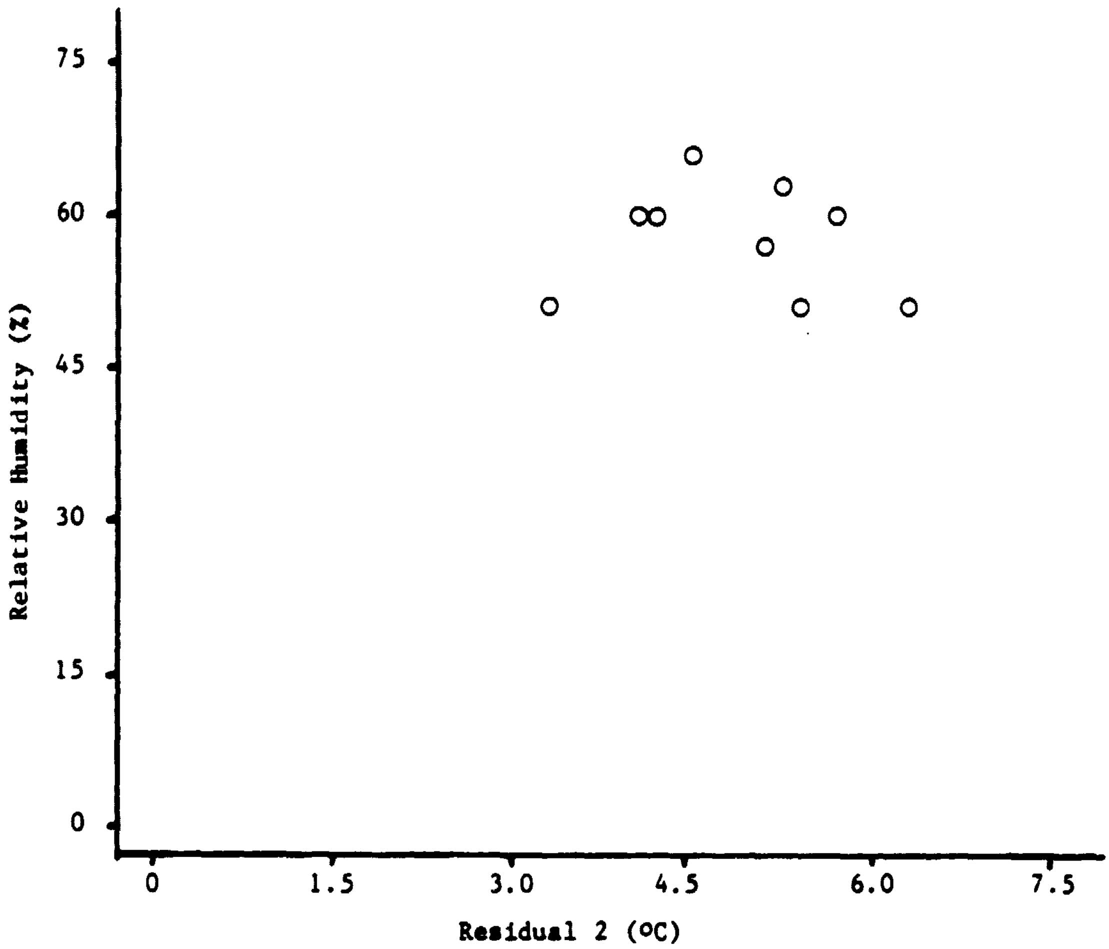

Figure 6. RELATIVE HUMIDITY VS. RESIDUAL 2 (MEASURED TEMP. MINUS HCMM TEMP WITHOUT 4.9 °C OFFSET)

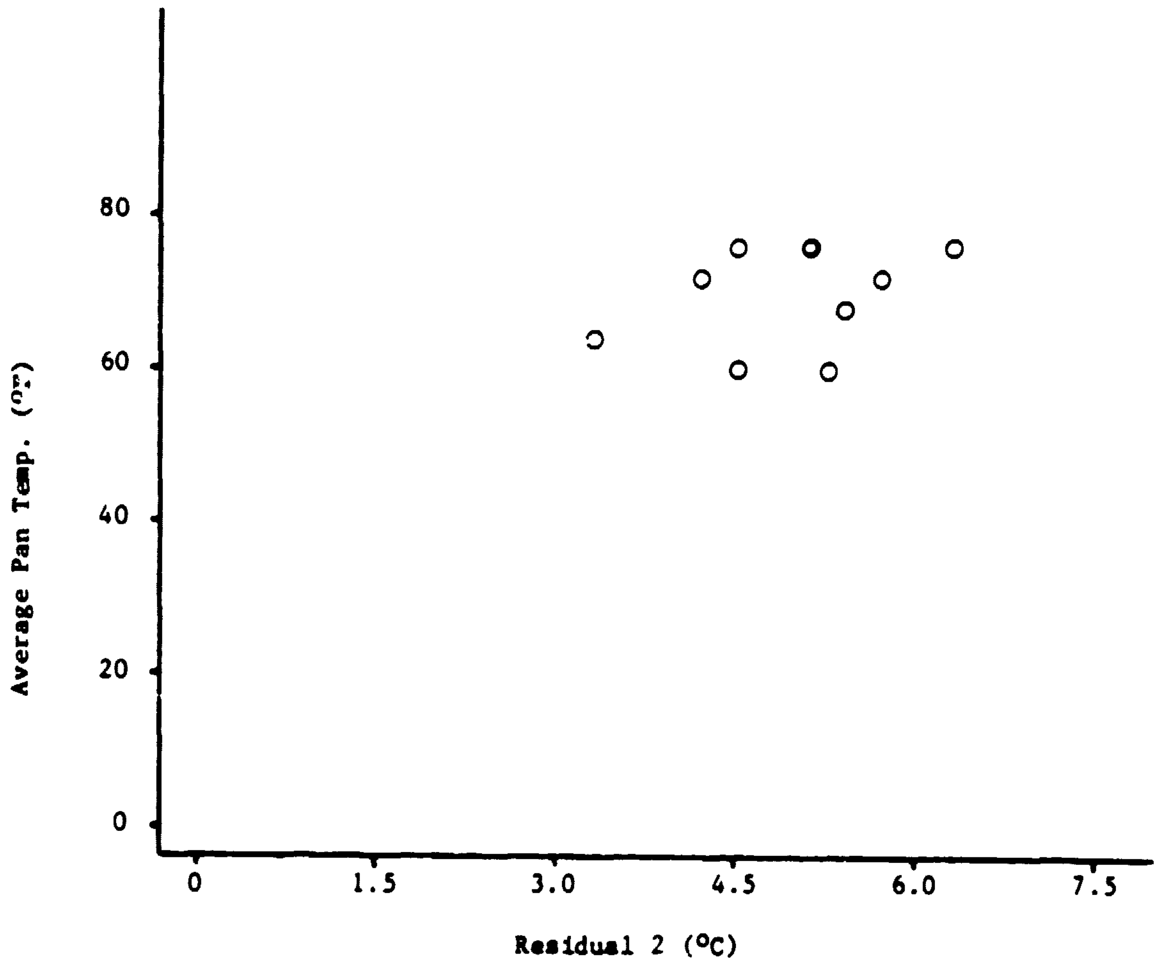

Figure 8. AVERAGE PAN TEMP. VS. RESIDUAL 2

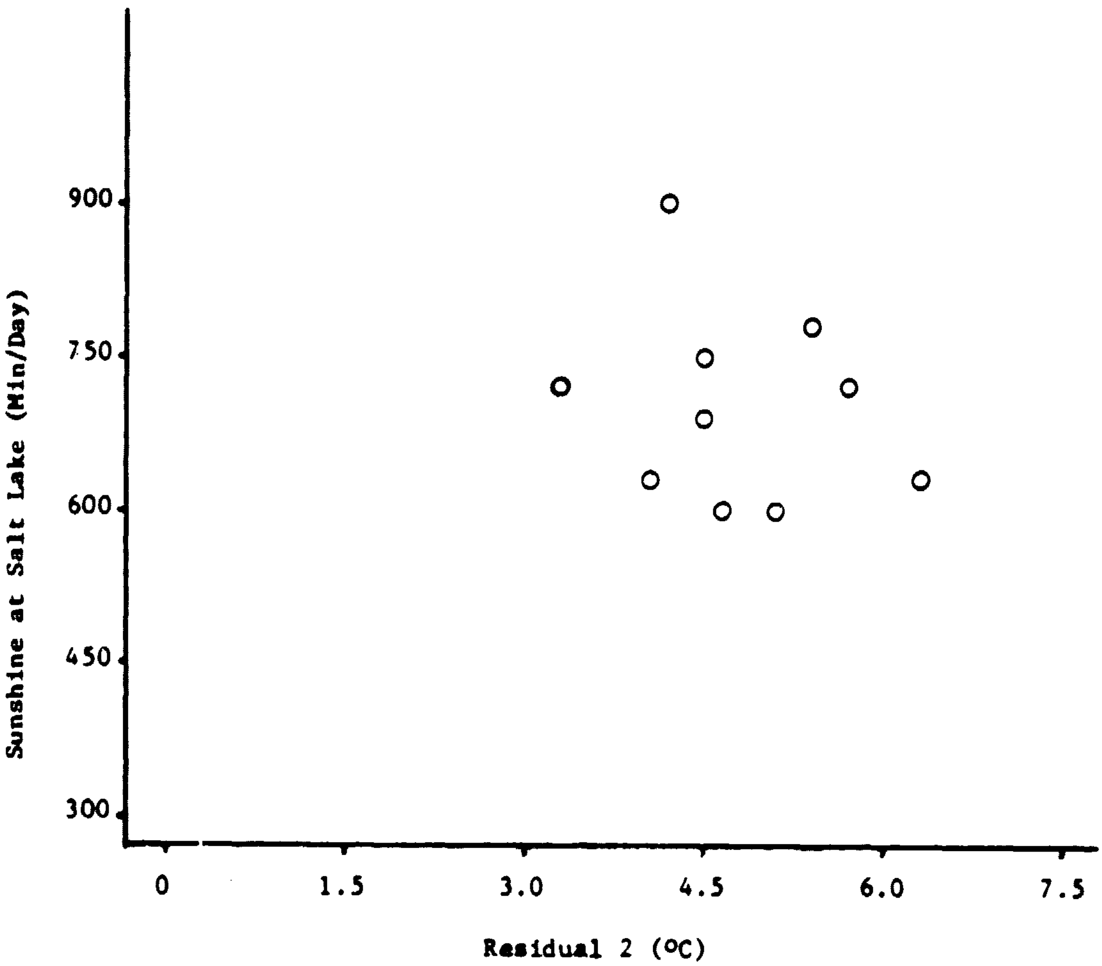

Figure 9. SUNSHINE VS. RESIDUAL 2

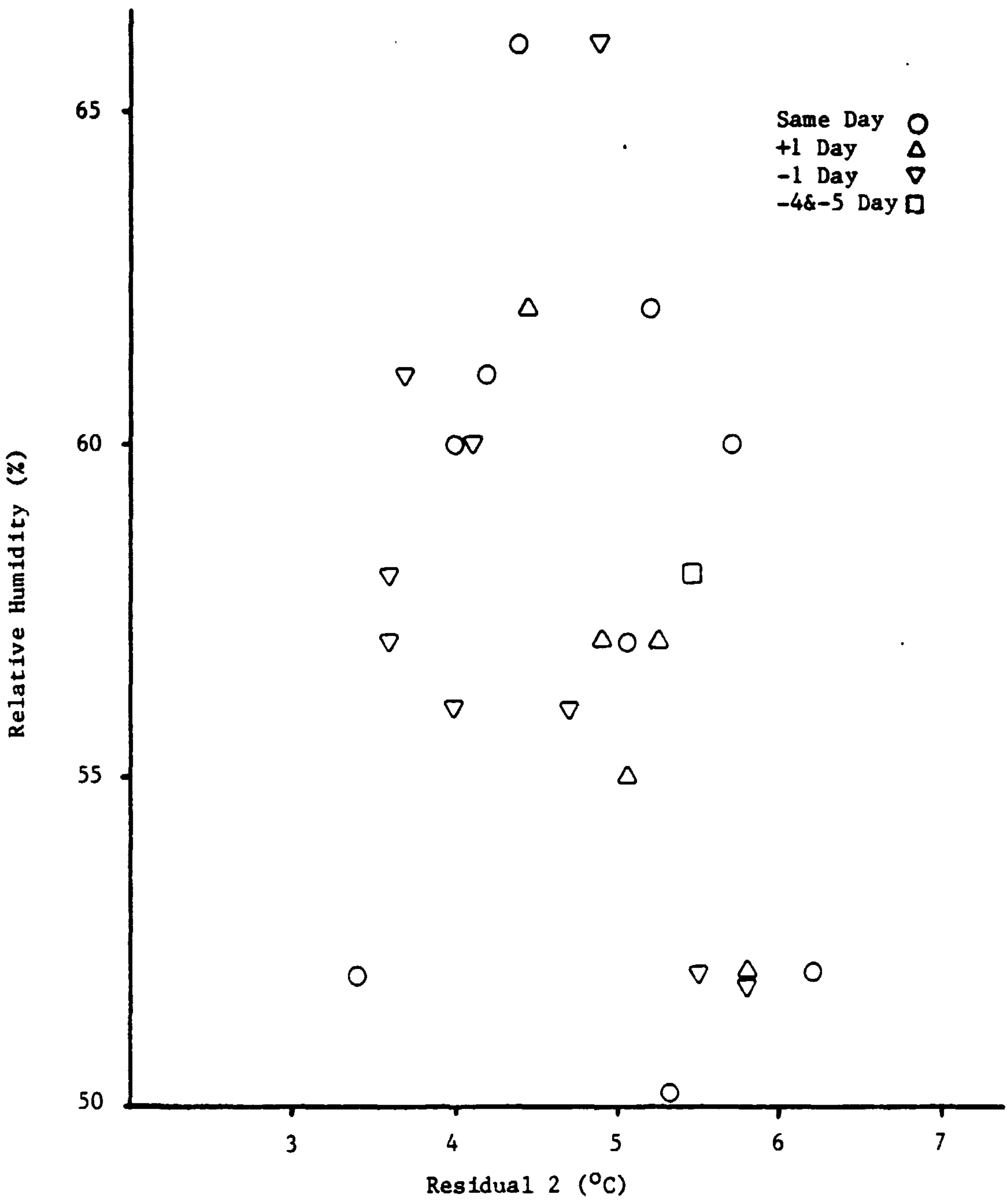

Figure 10. RELATIVE HUMIDITY VS. RESIDUAL 2 (ALL ± 5 DAY DATA)

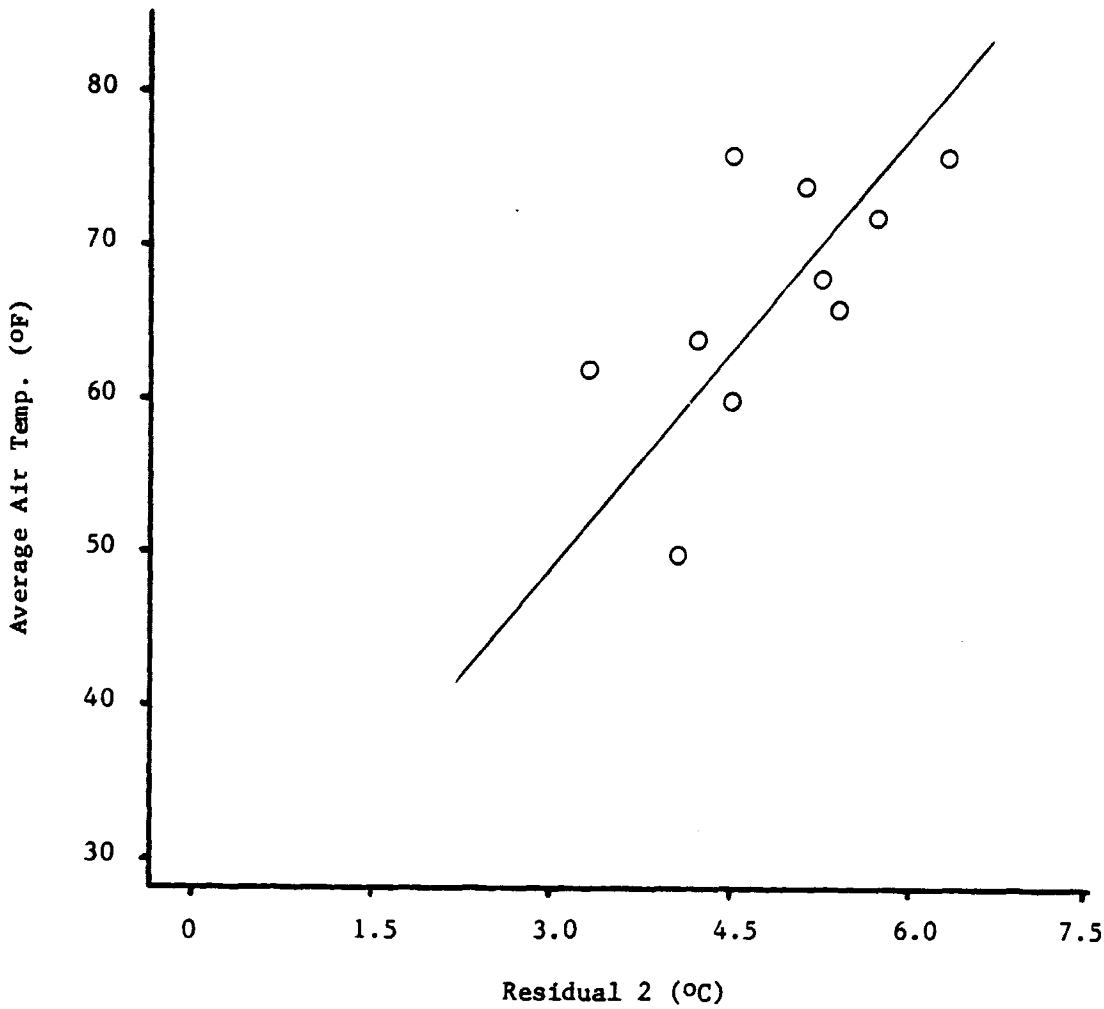

Figure 11. AVERAGE AIR TEMP. VS. RESIDUAL 2

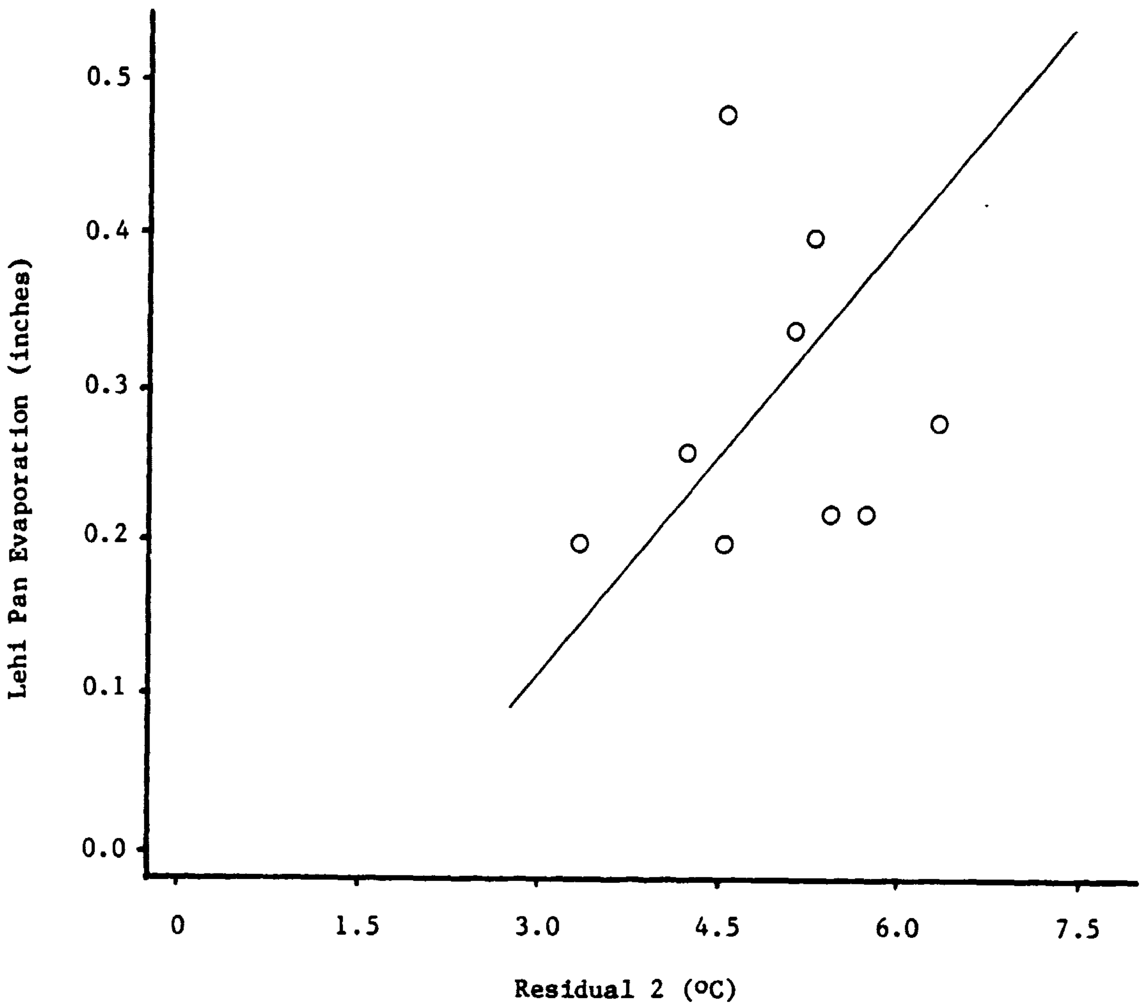

Figure 12. PAN EVAPORATION VS. RESIDUAL 2

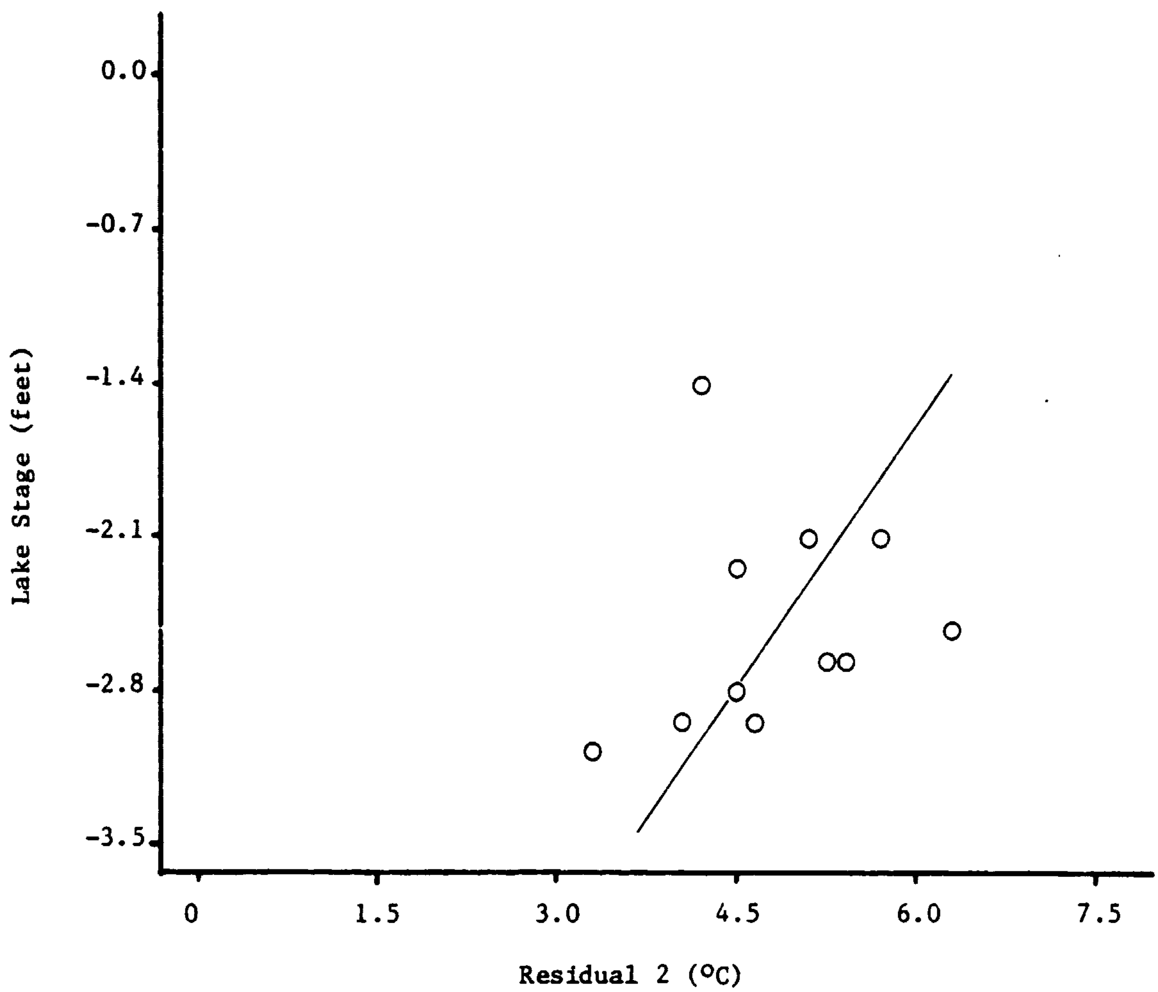

Figure 13. LAKE STAGE VS. RESIDUAL 2

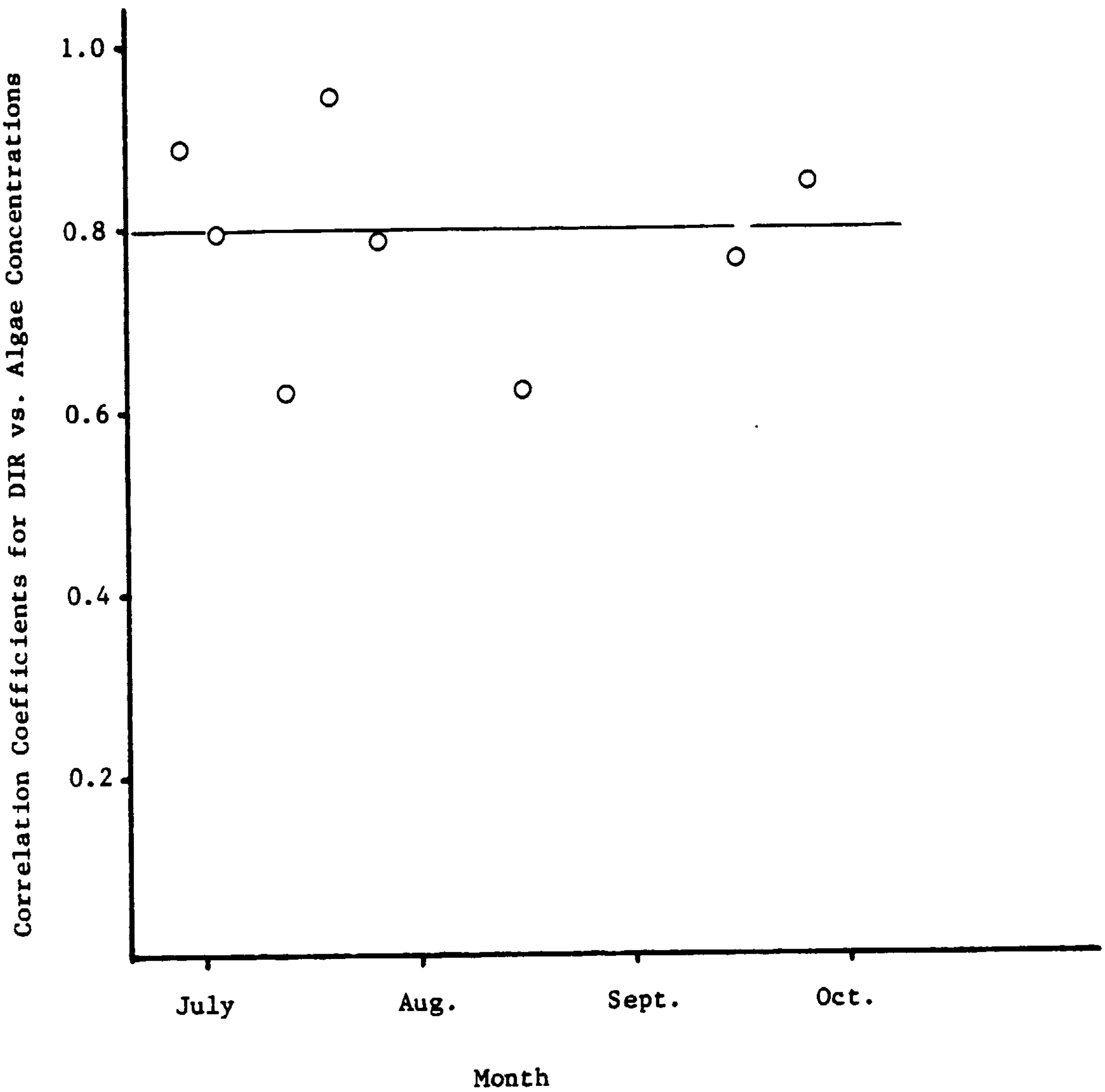

Figure 14. DIR AND ALGAE CORR. COEF. VS. MONTH

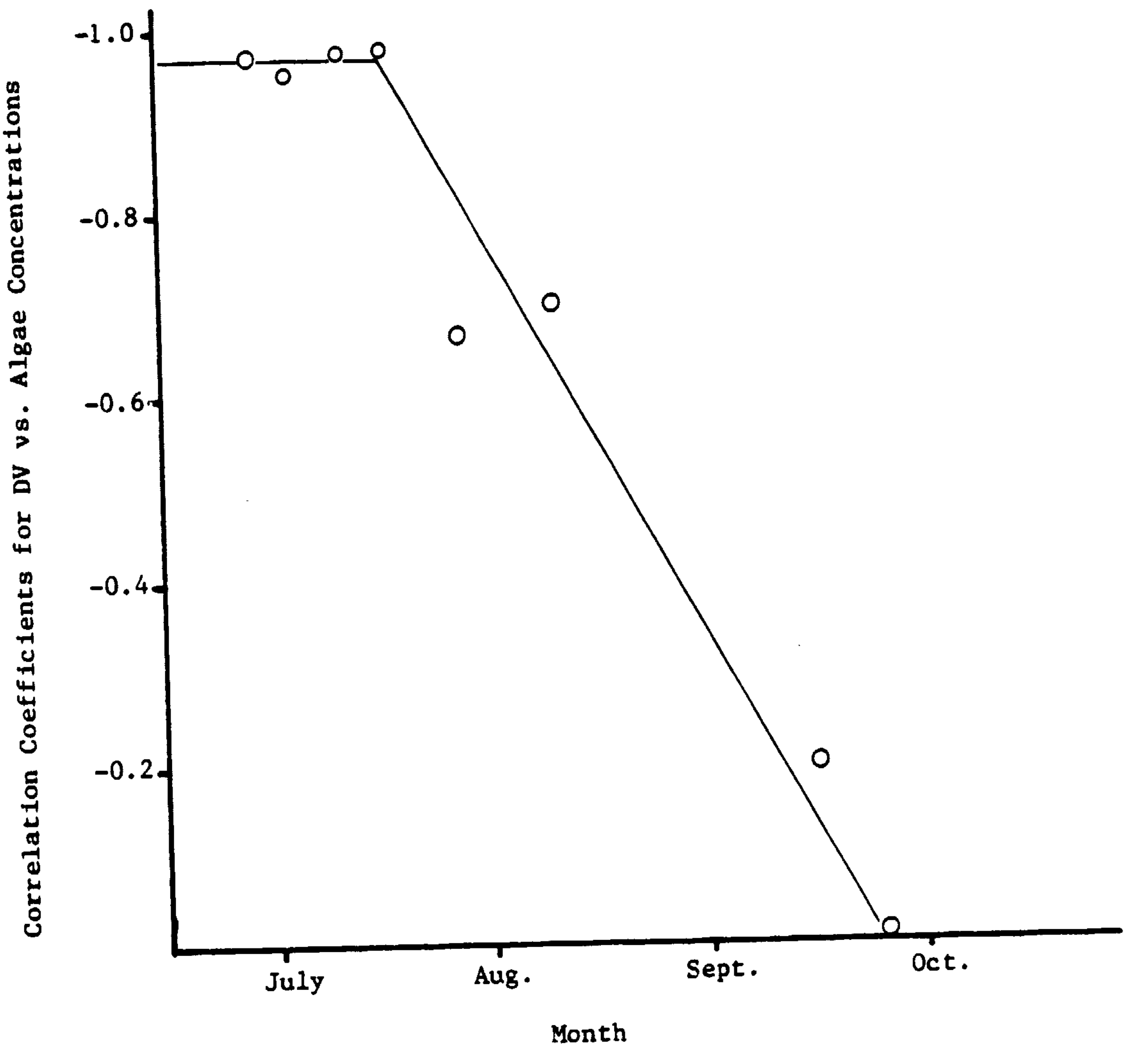

Figure 15. DV AND ALGAE CORR. COEF. VS. MONTH

methods for detecting algae. The first is to identify areas of high DIR readings on the lake surface relative to other parts of the lake. In Figure 16* for 6 July 1978, the warmer red, pink, yellow and green pixels indicate areas of high algae concentration. The second method is to compare DIR and DV measurements. Pixels which are warmer in Figure 16, the DIR image, and darker (less reflective) in Figure 17, the same day DV image, again depict high algae concentration areas.

Locating areas on the day and night IR scenes which are respectively warmer and cooler is the third method. An area of dense algae should behave much like a land mass, warmer than the surrounding lake during the day and cooler at night. The high positive correlation between algae and DIR and the high negative correlation between algae and NIR support this hypothesis. Figures 18 and 19, the 23 September 1978 DIR and NIR scenes respectively, also show this relationship. The lake's northwest corner is the warmest area on the lake during the day (Figure 18) and one of the coolest during the night (Figure 19) indicating the presence of higher concentrations of algae.

Predominant Species. During June, July, and early August the predominant species of algae on Utah Lake is Ceratium Hirundinella making up between 30% and 90% of the total plankton present. By late August, however, Ceratium has decreased to only about 2% of the population. During August, September, and October Aphanizomenon Flos-Alquae becomes extremely dominant and makes up over 90% of the total plankton. This change can be detected by the different reflective characteristics of the two species and the corresponding drop in the algae concentration versus DV correlations. This was shown in Figures 14 & 15. While the DIR readings continue to correlate well with

*Persons receiving reports without color prints may refer to those submitted to the technical administrator.

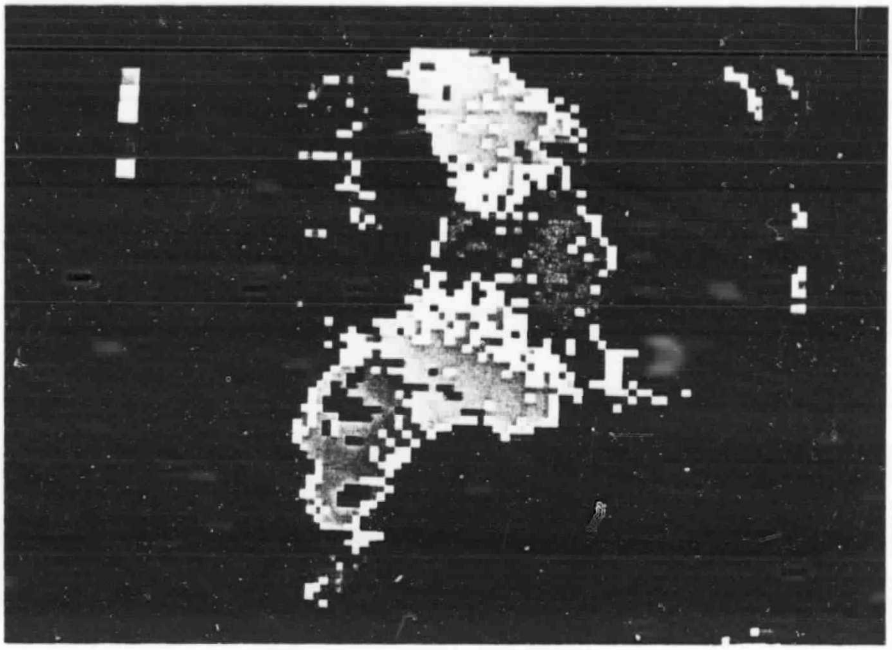

Figure 16. HCMM DIR INTENSITIES (6 July 1978)

Figure 17. HCMM DV INTENSITIES (6 July 1978)

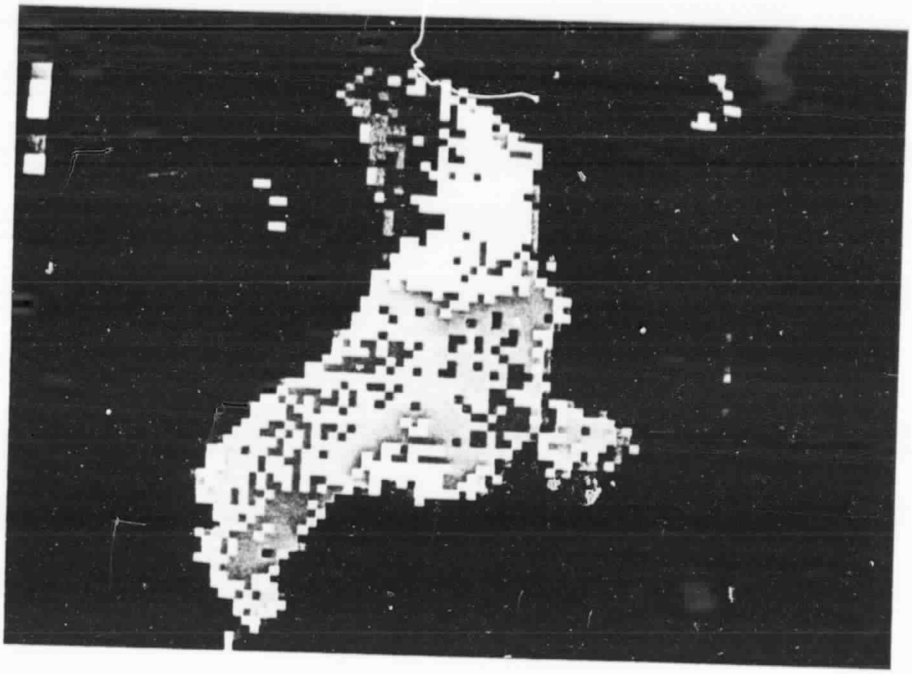

Figure 18. HCMM DIR INTENSITIES (23 SEPT 1978)

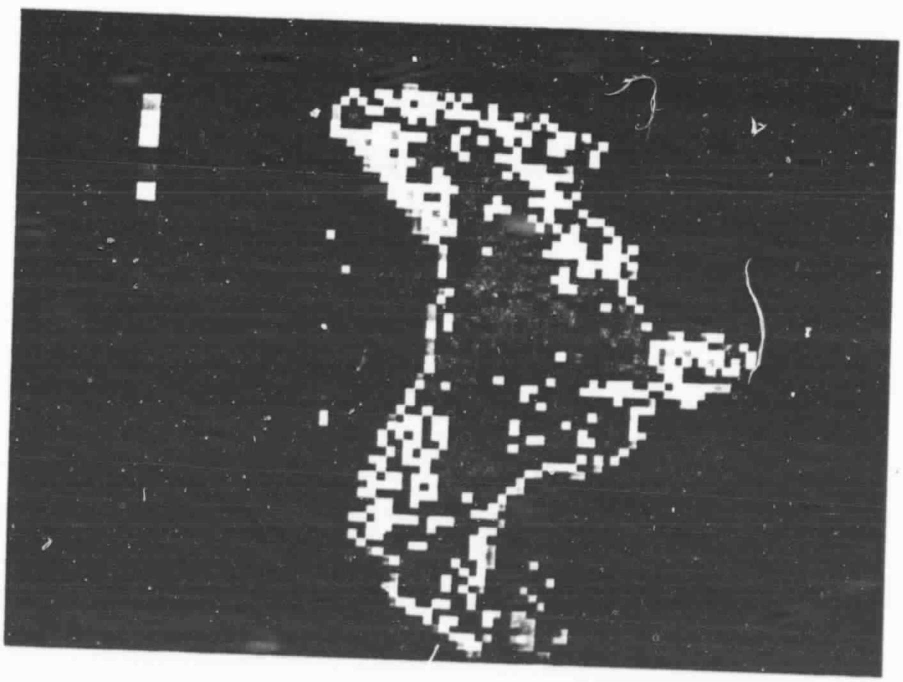

Figure 19. HCMM NIR INTENSITIES (23 SEPT 1978)

algae concentrations during this species change (Figure 14), indicating the continued presence of total plankton, the DV correlations change dramatically (Figure 15).

Algal Blooms. When the algae in the lake becomes sufficiently concentrated it forms mats on the surface. The algae are buoyed by trapped oxygen bubbles which give the mat a whitish appearance and make it very reflective. These mats or blooms can be identified on the DV imagery as very bright (reflective) areas within a darker (non-reflective) area of suspended, not floating, algae. The highly reflective small area in the center of the lake's northern half in Figure 20, the 4 September 1979 DV image, illustrates this phenomonon. The same day DIR image (Figure 21) indicates warm temperatures and hence high algae concentrations in the same general region but no "hot spot" corresponding exactly to the area of this bright mat.

Algae and Evaporation

Three evaporation pans with different species and concentrations have been set up adjacent to the Provo Airport official standard pan. These have been operational since mid-July, with periodic breakdowns. Pans have been inoculated with Utah Lake algae and with Anabena Flos-Aquae grown in the laboratory. The Anabena has caused some problems because it doesn't float unless some debris is present upon which to attach itself.

Lake sample inoculations have different algae species during different seasons. At this time (late August) the Microsystis have died and the Anabena and Aphanizomenon are predominant. Aphanazomenon float on the pan and lake water surface in mats. However, passing storms have mixed the algae into the water column making sample collection difficult. Biomass measurements of the samples are being made in the BYU Environmental Analysis Laboratory. Data on the effects of varying algae concentrations on evaporation will be available for the next quarterly report.

Figure 20. HCMM DV INTENSITIES (4 SEPT 1979)

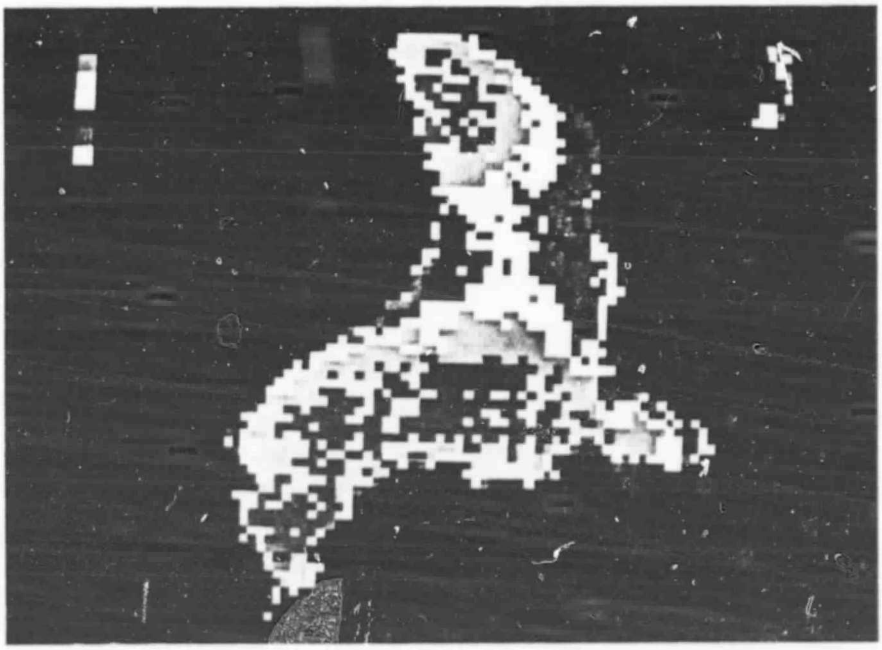

Figure 21. HCMM DIR INTENSITIES (4 SEPT 1979)

<u>Evaporation and HCMM Temperatures</u>

An effort has been made to develop a model for evaporation estimation based on the HCMM data. Surface temperature is a key parameter in evaporation, and meaningful direct and indirect relationships between them must exist. As of the end of the second quarter significant progress has been made and further break throughs are anticipated, particularly in the area of developing windspeed functions for Dalton type evaporation models.

Figures 22 and 23 show HCMM data plotted versus same day evaporation and 2 day average evaporation respectively. The HCMM data are DIR intensities converted to temperatures (temporarily in °F) which are averages for the entire lake. The conversion incorporates the + 4.9 °C offset to the HCMM User's Manual equation. Same day evaporation means the evaporation recorded at the Lehi pan on the day of the HCMM overflight and average evaporation means the same day and previous day evaporation values averaged. Averaging was done to help eliminate effects of sudden changes in recorded pan evaporation and resulted in slightly better correlations.

Evaporation clearly increases with surface temperature. Although linear equations have been determined and are given, a second order relationship may fit the data better. The correlation coefficients of 0.82 and 0.86 respectively are reasonably good. More data is anticipated.

HCMM night temperatures (with the + 4.9 offset) were also plotted against average evaporation as shown in Figure 24. This correlation is even better than the day data with a coefficient of 0.95. The slopes of the linear regression equations for day and night are similar. More night data is also expected.

In order to relate pan evaporation to Utah Lake evaporation a monthly pan coefficient is generally applied. No coefficients have been applied to the evaporation data analyzed in the study to this point. However, the

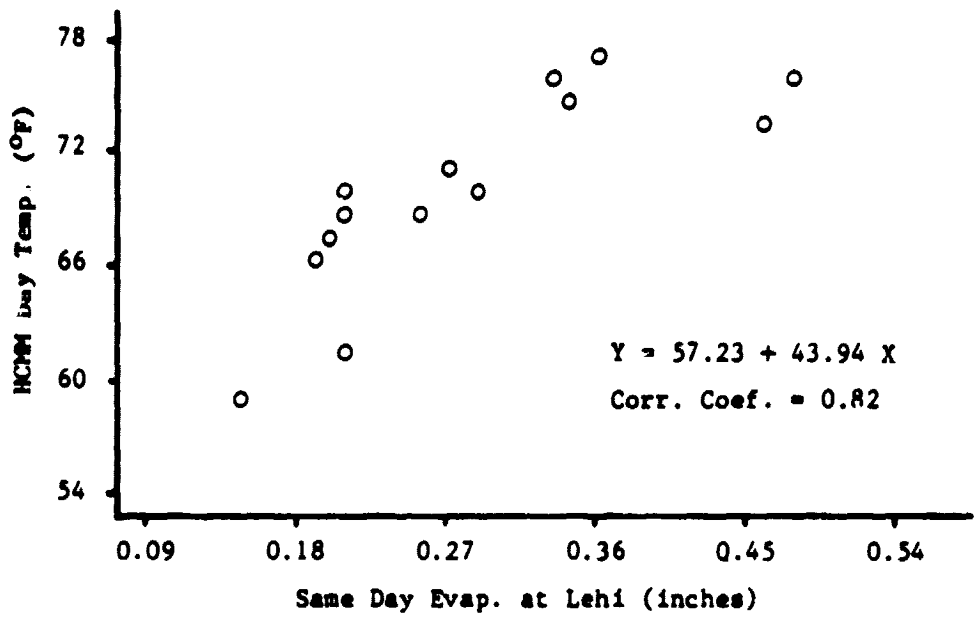

Figure 22. HCMM DAY TEMP. VS. SAME DAY EVAP.

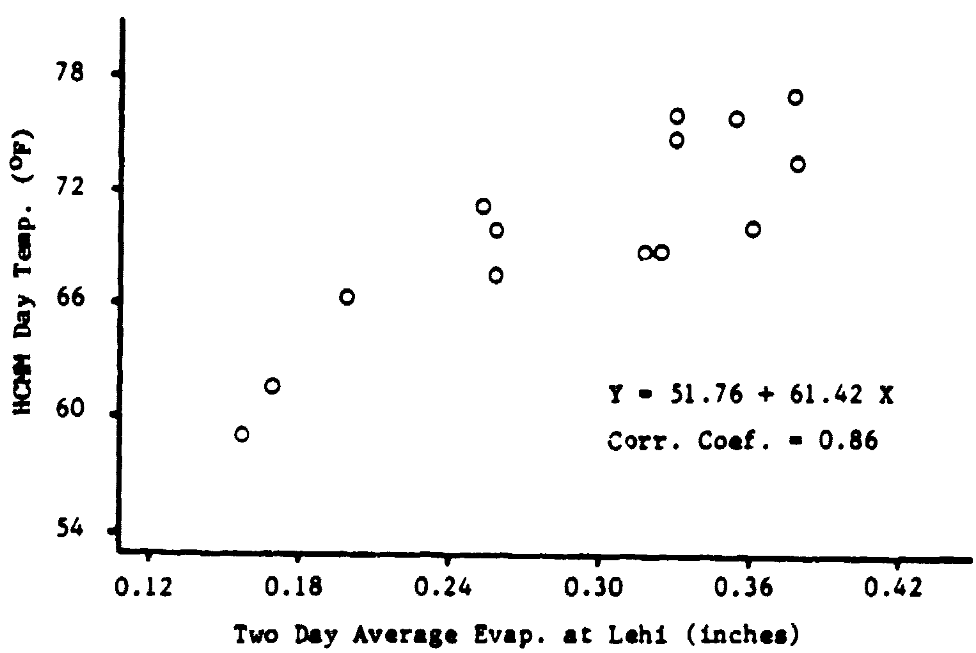

Figure 23. HCMM DAY TEMP. VS. AVE. EVAP.

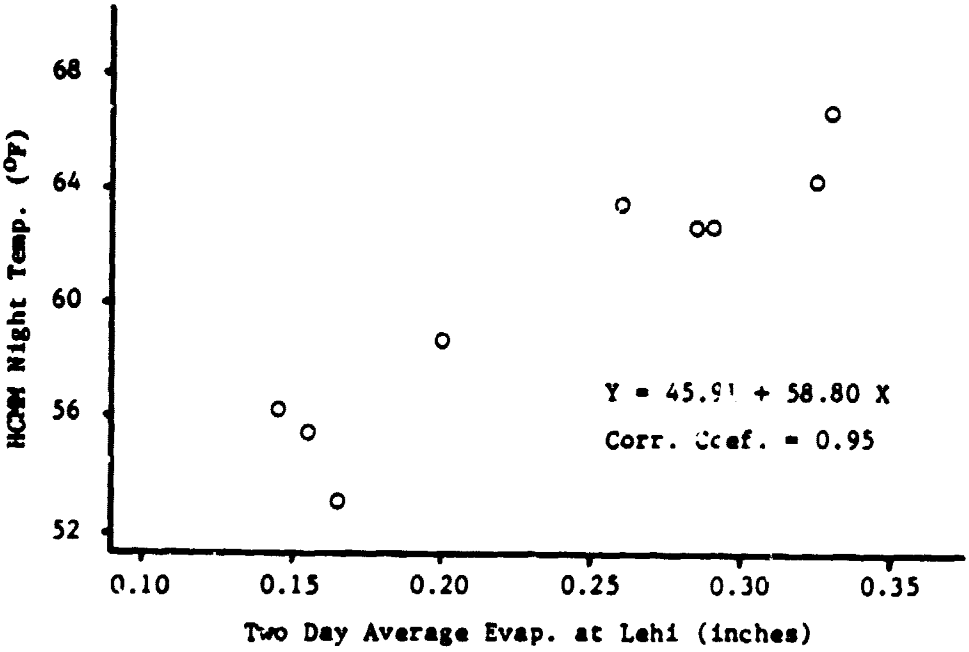

Figure 24. HCMM NIGHT TEMP. VS. AVE. EVAP.

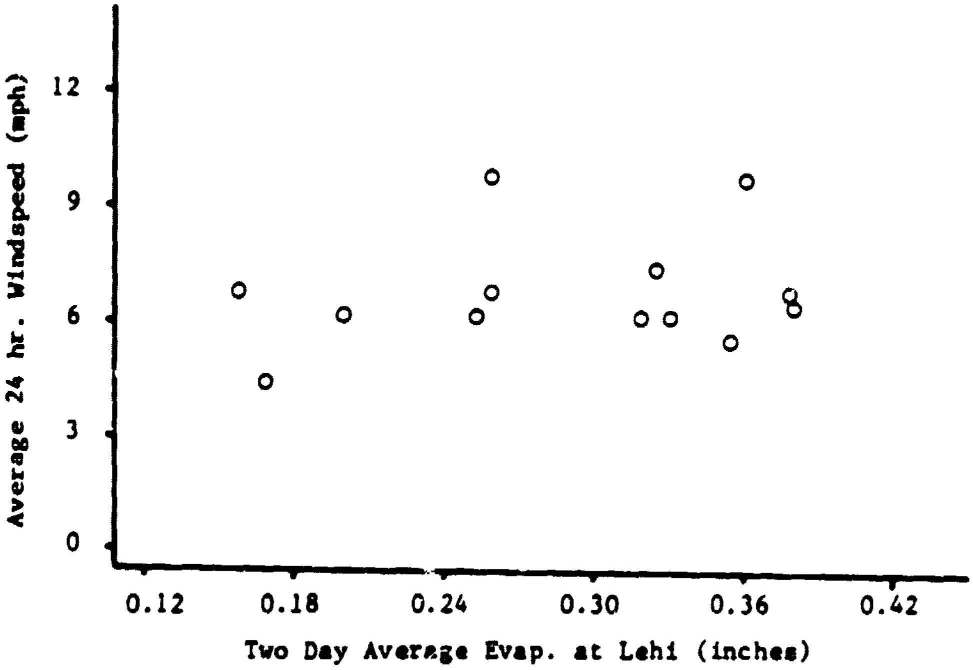

Figure 25. AVE. WINDSPEED VS. AVE. EVAP.

various monthly coefficients which have been utilized will be investigated and the results compared. Also monthly evaporation values derived from water budgets and climatolological modeling will be correlated with the HCMM data.

It is not clear if wind is an important factor on the evaporation from Utah Lake because the lake is so large. However, Provo Airport, hourly windspeed data taken at 2 meters have been investigated for possible correlations. Tabulated windspeed is the average of the 24 hourly values just prior to the HCMM overflight at 1:30 p.m. Figure 25 shows that the evaporation is apparently not strongly dependent upon wind. HCMM temperatures versus wind looks similar. This may be somewhat misleading, however, because the windspeed values on HCMM overflight days are relatively low and fit within a small range of from 5 to 10 mph. The higher windspeeds necessary for a more complete analysis correspond to stormy periods which eliminate the possiblity of usable HCMM imagery.

Air and HCMM Temperatures

The relationship between air temperatures and average Utah Lake water surface temperatures has been investigated. Response of the surface water to convective heating and cooling was noted. The diurnal air temperature changes compared to the water temperature changes were also noted. Maximum air temperatues (at Provo Airport) correlate well with HCMM day surface temperatures as shown in Figure 26. As expected, air temperatures are always larger.

Minimum air temperatures are always lower than HCMM night surface temperatures and the correlation is slightly lower than for daytime data (Figure 27). The typical time of minimum air temperature (~5 am) does not correspond as closely to the HCMM overflight time (~2:30 am) as during the day which might explain the poorer correlation. Preliminary analysis of the diurnal variation of the data indicates that the surface temperature

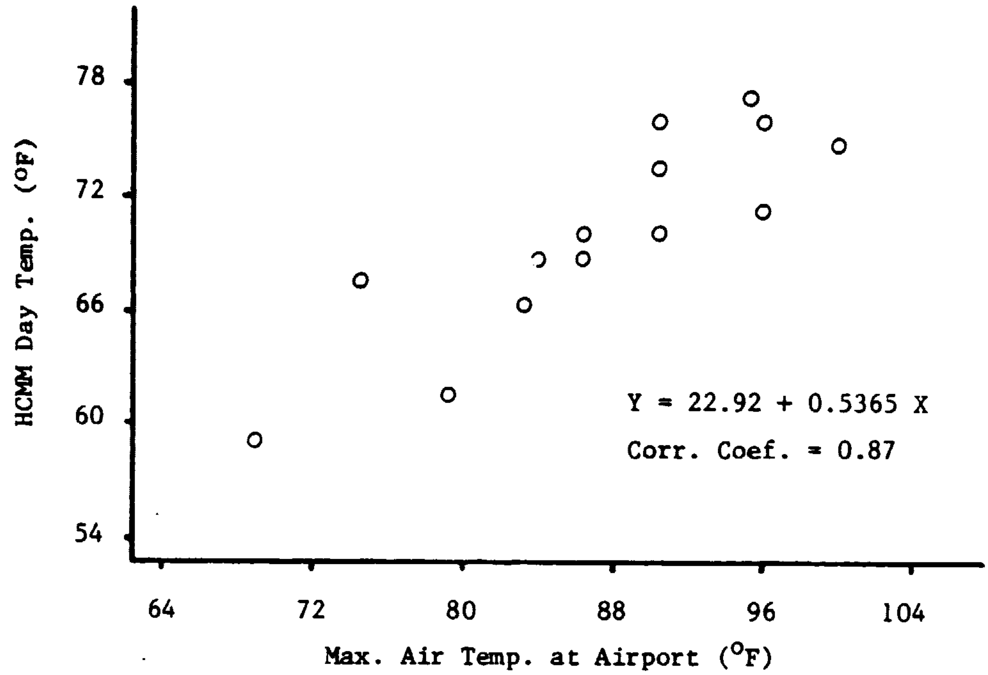

Figure 26. HCMM DAY TEMP. VS. MAX. AIR TEMP.

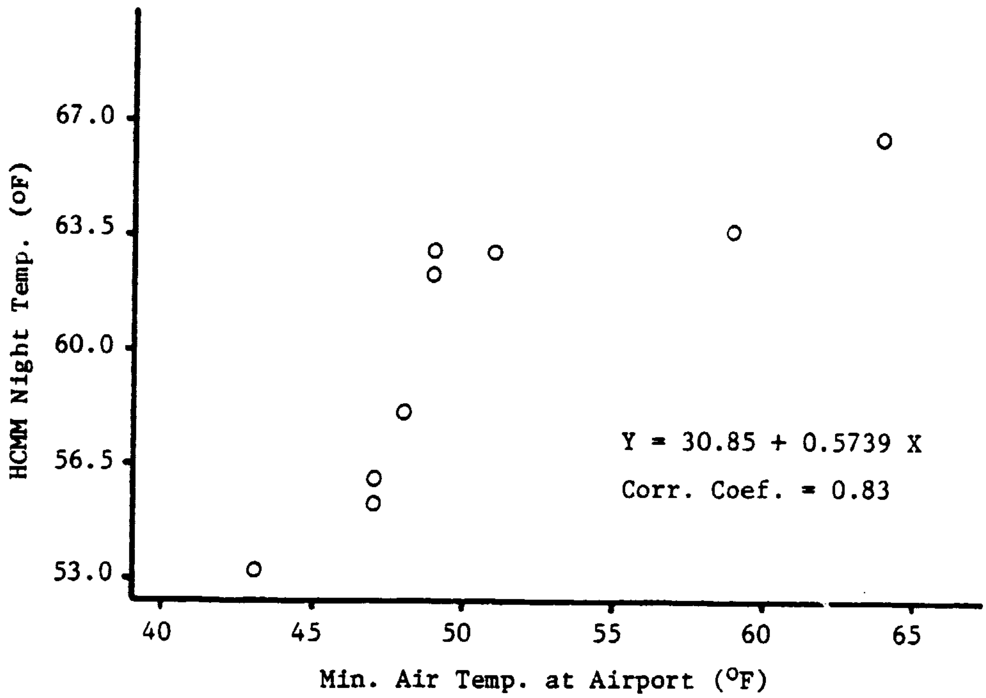

Figure 27. HCMM NIGHT TEMP. VS. MIN. AIR TEMP.

changes by 7 to 10°F while the air temperature changes by 27 to 38°F. The consistency and interdependency of the day and night correlations are indicated by the fact that the air temperature change is approximately 3.8 times larger than the water temperature change for both the high and low temperatures.

Lake Segment Temperatures

Utah Lake's four segments; Goshen Bay, Provo Bay, Central Lake, and North Lake were shown in Figure 5. Average HCMM surface temperatures were determined for each segment and plotted against the whole lake average temperatures in Figures 28, 29, 30, and 31 respectively. All temperatures incorporated the + 4.9°C offset. All the correlations are very high. However, the two segments where algae is more common, PB and NL, exhibit slightly lower correlations, 0.94 versus 0.99. This is because of greater algae, and hence, temperature fluctuations in these segments as compared to the whole lake.

Apparently for similar reasons the linear regression equations for PB and NL also differ slightly from GB and CL in both slope and intercept. The former two segments have smaller slopes (~0.9) than the later two (~0.95). All of the intercepts are positive, however, PB and NL intercepts are larger (~5°F) than the intercepts for GB and CL (~2°F).

Thermal Springs

Using the combinations of DIR, NIR, and DV imagery has led to the possible identification of thermal springs in Utah Lake. NIR data throughout the study period have indicated a warm area in the southwestern region of the lake (western Goshen Bay). Figure 32 of the 4 September 1979 NIR is a typical example. Corresponding DIR images (e.g., Figure 21) don't show this because of the solar radiative and atmospheric convective heating of the surface water. Winter DIR data, such as 14 November 1979, (Figure 33)

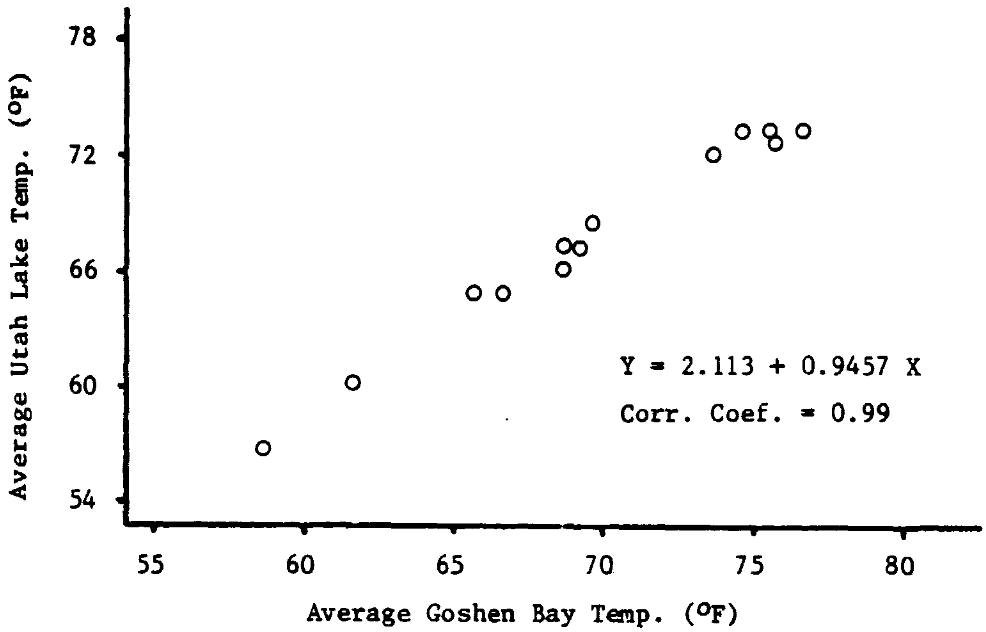

Figure 28. AVE. UL TEMP. VS. AVE. GB TEMP.

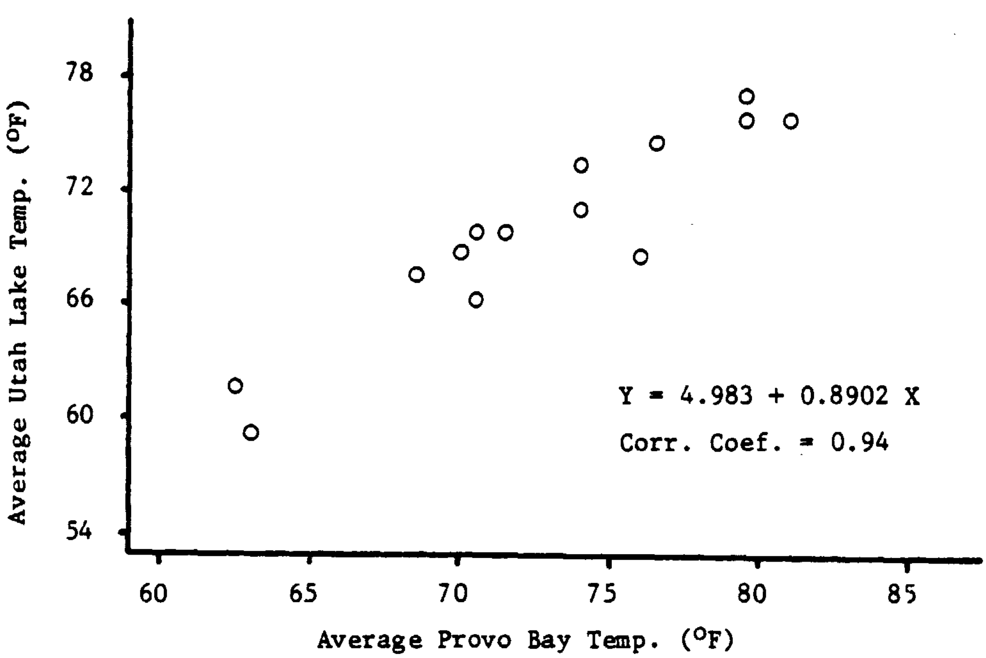

Figure 29. AVE. UL TEMP. VS. AVE. PB TEMP.

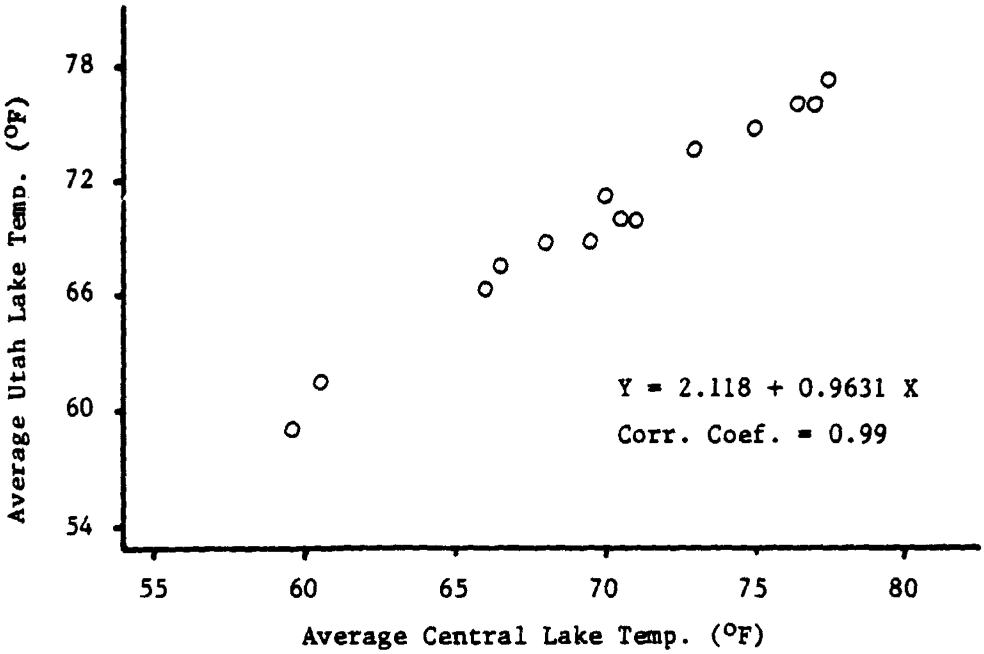

Figure 30. AVE. UL TEMP. VS. AVE. CL TEMP.

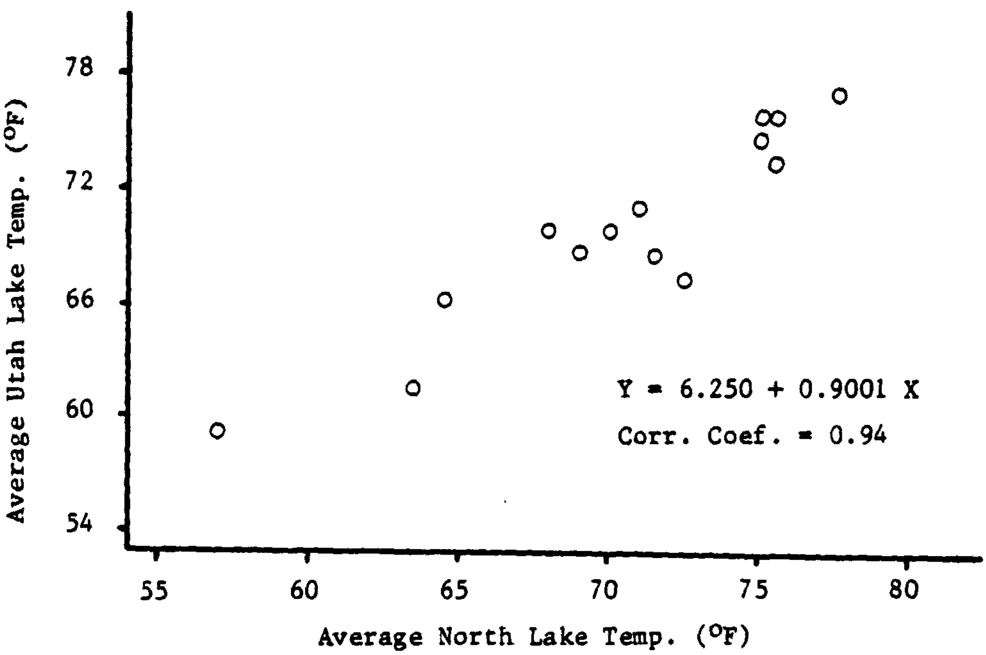

Figure 31. AVE. UL TEMP. VS. AVE. CL TEMP.

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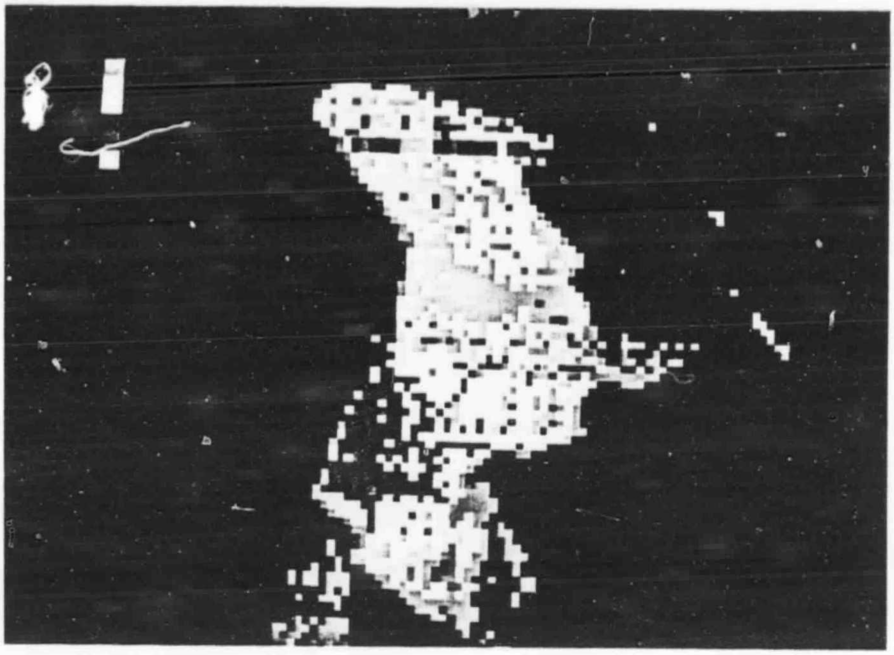

Figure 32. HCMM NIR INTENSITIES (4 SEPT 1979)

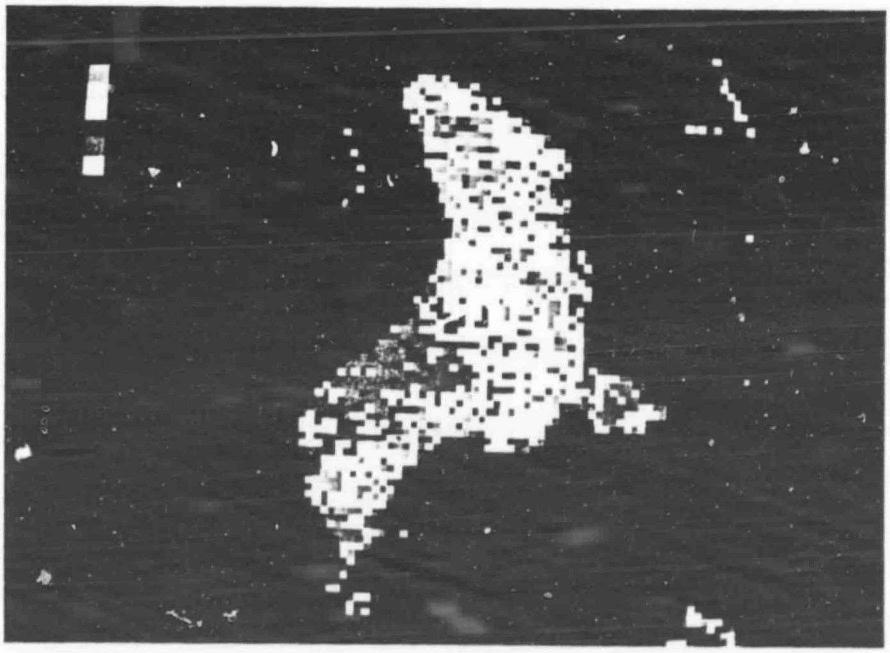

Figure 33. HCMM DIR INTENSITIES (14 NOV 1977)

also shows this same warm area. Previous studies on Utah Lake have located two faults in this region and several thermal springs have been identified along each.

Groundwater

Correlations of depth to groundwater versus HCMM surface temperature have been investigated. In the first quarter report a semilog plot of these two parameters was given (Figure 10). A trend of lower temperatures with higher groundwater could be argued, but the extent of scatter in the data makes such a conclusion statistically uncertain. Many different methods of manipulating and analyzing that data were utilized, but the best correlation coefficients obtained were in the 0.3 to 0.4 range. One of the major problems was the lack of reliable ground truth measurements.

Because of the uncertainty in quantitative results, a qualitative approach has been taken. Ten transects through distinctive regions in the study area which showed qualitatively high and low ground water were plotted. Twelve different days of HCMM DIR or NIR intensities for the same transects were also plotted and compared. Examples are shown in Figures 34 and 35 for 14 July 1979 and 9 August 1979 respectively. All of these graphs are presently being analyzed. The results so far are again inconclusive and confusing.

In Figures 34 and 35 the HCMM intensities both increase and decrease with higher groundwater. In fact, it appears that more often the intensities (surface temperatures) rise with higher groundwater. Obviously other factors, such as vegetation and soil types, are having a major influence. Transects without vegetation and with homogeneous surfaces are being more intensively studied. More emphasis is being placed on this aspect of the total project in order to establish meaningful conclusions.

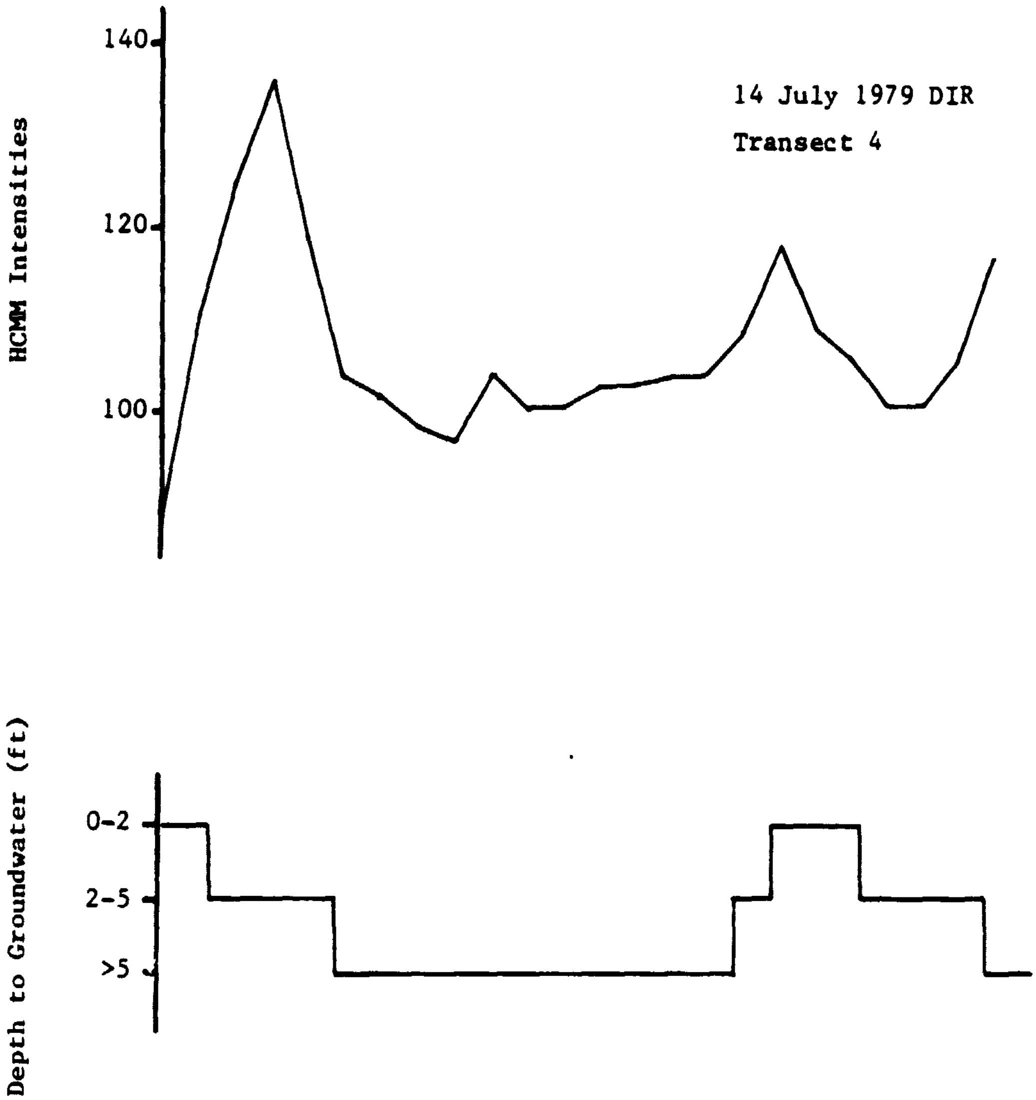

Figure 34. HCMM INTENSITIES VS. DEPTH TO GROUNDWATER

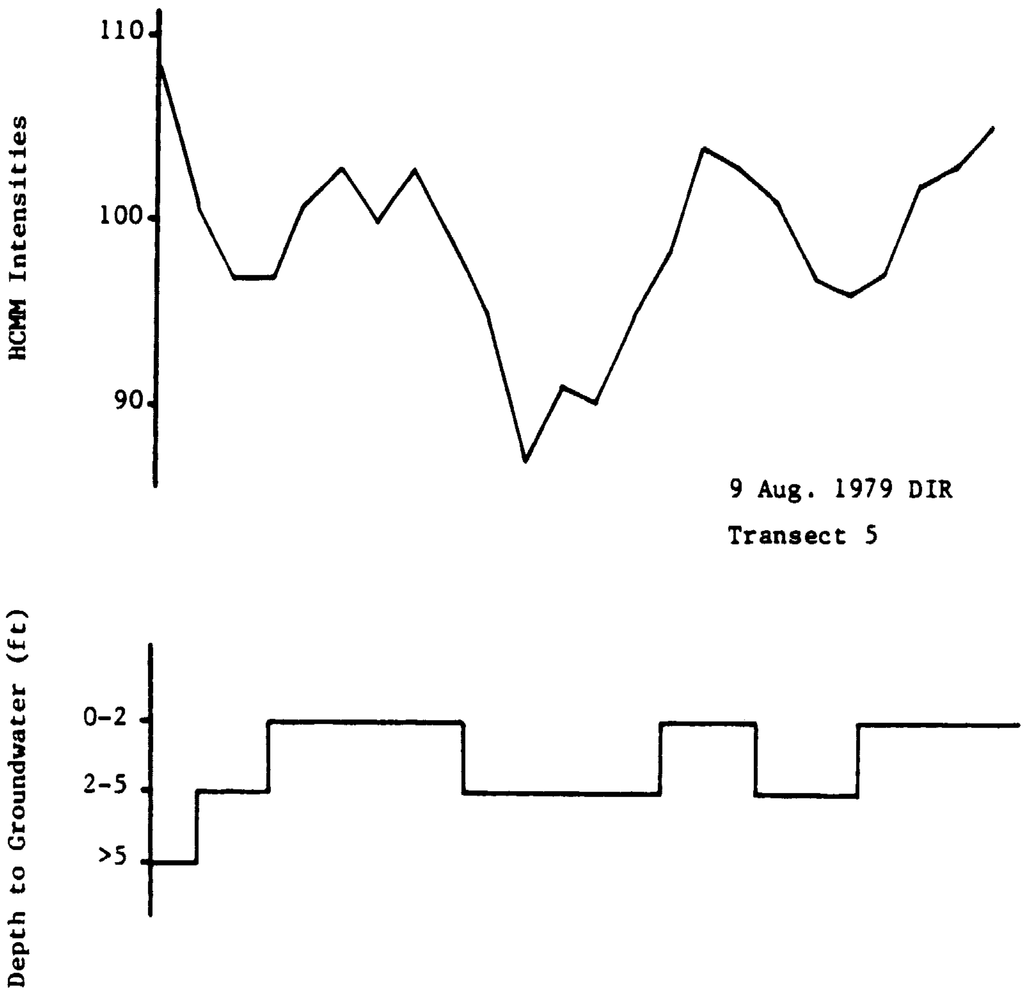

Figure 35. HCMM INTENSITIES VS. DEPTH TO GROUNDWATER

Second Quarter Expenditures

(Since 1 June 1981)

Principle wages	$2674.60
Research Assistants (Graduate Student) wages	2477.75
Fringe Benefits	618.28
Computer	180.75
Travel	257.65
Indirect Costs	2576.18
Total Expenditures	$8785.21